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Procedia Engineering 146 (2016) 224 – 230

Procedia Engineering

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8th International Cold Climate HVAC 2015 Conference, CCHVAC 2015

Numerical Analysis of Infectious Ward Air Exchanges Rate

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Abstract

At present, our country regulated that the air exchange rate in infectious ward should be 10 to 40 times per hour. The United States, Australia, Britain regulated that the air exchange rate in infectious ward should be not less than 12 times per hour, under the conditions of restriction, the air exchange rate should be not less than 6 times per hour. However, for different forms of ventilation and room types, people need to specific study in order to achieve the reasonable air exchange rate. By the method of numerical simulation, with particle size of 5μm and 20μm as example, in the condition of the wall attached jet, the paper researched the effects of different air exchange rate for discharging indoor pollutant efficiency.

Peer-review under responsibility of the organizing committee of CCHVAC 2015

Keywords: *Numerical analysis;Infectious ward;air exchange rate; Wall attached jet;aerosol particles*

1. Introduction

During the SARS outbreak in 2003, 20% of the infected group is medical personnel in our country [1]. The hospital has become the main place where the SARS spread. Therefore, improving the quality of air in the wards, which can not only protect the health of medical staff, but also can help the patients recover. According to the relevant provisions of our country promulgated, ventilation rate of infectious ward is 10-40 times per hour [2], under the conditions of restriction, the air exchange rate should be not less than 6 times per hour [3]. But the increase in ventilation rate will affect indoor heat and wet environment, increase the energy consumption of air conditioning, is not conducive to the patient's recovery. Therefore, it is necessary to study the infectious ward ventilation rate. This paper through the method of numerical simulation, studies under different ventilation rates, the patient produces droplets trajectory and the change of the concentration of aerosol particles, from the perspective of the patient's comfort and control of pollutants within a reasonable design infectious ward air conditioning ventilation rate.

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Peer-review under responsibility of the organizing committee of CCHVAC 2015
doi:10.1016/j.proeng.2016.06.378

2. Methods

2.1.Math model

The literature 4 points out that the indoor air flow should be used in RNGK-Ɛ turbulence model [4].The RNGK-Ɛ model and standard K-Ɛ model are similar, there are following improvements:

- The RNGK-Ɛ model adds a condition in Ɛ equation, effectively improve the accuracy;
- Considering the turbulent eddies, the aspect of accuracy is improved;
- Standard K-Ɛ model is a kind of high Reynolds number, and the RNG model provides the analytic formula a considered low Reynolds number flow viscosity. So this paper uses the RNGK-Ɛ turbulence model.

The particle trajectory was solved based on Lagrange coordinates [5]. The Lagrange method can solve a single particle (group) equation of motion (by Newton's second law of motion) to get the velocity of particles. Particles in the flow field are affected by multiple forces together. Among them, for the small aerosol particles, bassett force, pressure gradient force and mass force can be negligible, but Saffman force will not be ignored. As a result, the trajectory equation for the end form is:

$$\frac{du_p}{dt} = \frac{18\mu_a}{\rho_p d_p^2 c_c}(u - u_p) + \frac{g(\rho_p - \rho_a)}{\rho_p} + Fs \tag{1}$$

In the equation, the u_p is the particle velocity, m/s; t is the time, s; μ_a is the air viscosity, Pa·s; the ρ_p is particle density, Kg/m³; d_p is particle diameter， m; c_c is correction coefficient; u is air velocity, m/s; ρ_a is air density, Kg/m³; Fs is Saffman force, N.

Particle concentration equation is:

$$c = \frac{M\sum_{i=1}^{m} dt}{V} \tag{2}$$

In the equation, c is the average mass concentration of particles in a cell; M is the flow of each trajectory; dt is particles in the cell residence time; m is track number; V is the cell volume.

2.2.Physical model

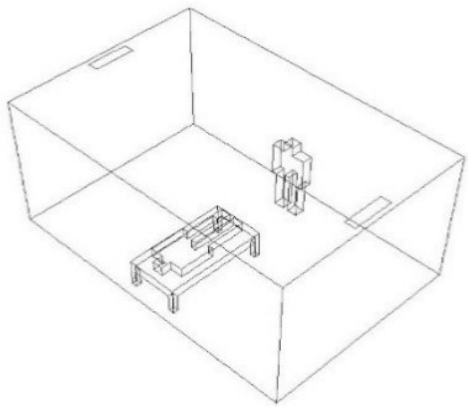


Figure 1. Physical of the infectious ward

As shown in figure 1, the ward gerometry size is 6m×3m×3m. Doctor and patient model are palced in the middle position. The human body model consists of head, body and limbs of three parts. Its height is 1.70m. Using a quadrilateral 0.2m×0.1m instead of mouth and nose.

2.3.Boundary conditions

In the simulation, the air turbulence model is RNGK-Ɛ model, and spread of aerosol particles is DPM model. Boundary conditions and parameters setting directly influence the accuracy of the simulation. The air inlet adopts velocity inlet and the air outlet adopts outflow. Specific boundary conditions are shown in table 1.

Table 1. Description of boundary condition

Boundary name	Detail description
Wall attached jet air inlet	Velocity inlet, 0.4m/s, turbulence intensity 10%,temperature 298K, geometry size 0.2m×0.8m
Wall attached jet air outlet	Outflow
Body model surface	Wall, temperature 308K
Aerosol particle	Density 800Kg/m³, temperature 310K, velocity 0.5m/s

Respectively ventilation rate set to 10 times per hour, 15 times per hour and 20 times per hour. The flow rate of 5 microns particle is 0.085μg/s, and the flow rate of 20 microns particle is 1.6μg/s.

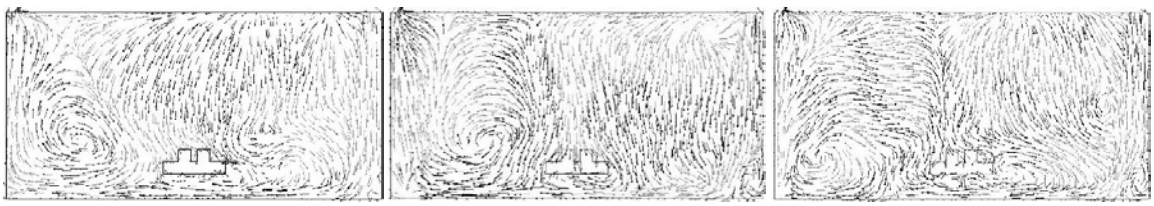
2.4.Model assumptions

Do the following assumptions in the simulation:

- Fluid flows in steady turbulent flow;
- Ignoring the evaporation of aerosol particles;
- No collision and fusion between particles;
- Ignoring particles effects on steady turbulence model;
- All particles are regard as uniform spheres.

3. Results

3.1.Simulation of wall attached jet

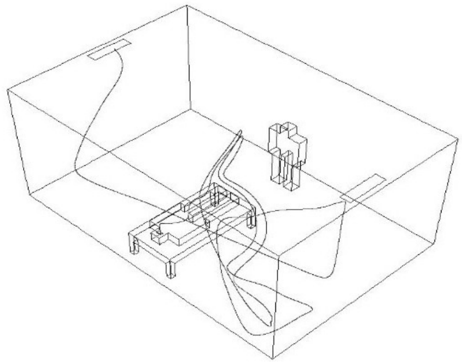


(a) 10 times/h (b) 15 times/h (c) 20 times/h

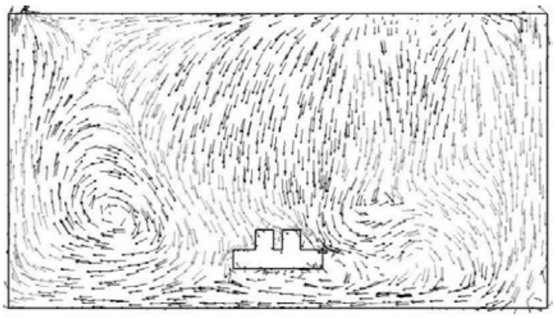
Figure 2. Velocity vector at z=0

Figure 2 shows the wind velocity vector diagram under different air exchange rates in wall attached jet infectious ward. As shown from the figure, the three air exchange rates can achieve the effect of wall attached jet. Fresh air moving along the right side of the wall to the ground, and at the lower part of the ward form flow field which is similar to displacement ventilation. Therefore, wind speed has no obvious effect on attached. When supply air wind speed is larger, the ward forms a larger pressure difference, which can produce great influence of human activity area. When the air exchange rate is 20 times per hour, the middle area air move to air supply side, then move to ground and mixed with indoor air. The whole process is not mixed with the fresh air. When the air exchange rate is 10 times per hour, middle area air to air supply side movement is not obvious. So, increasing the supply air wind speed is beneficial to control the air flow direction.

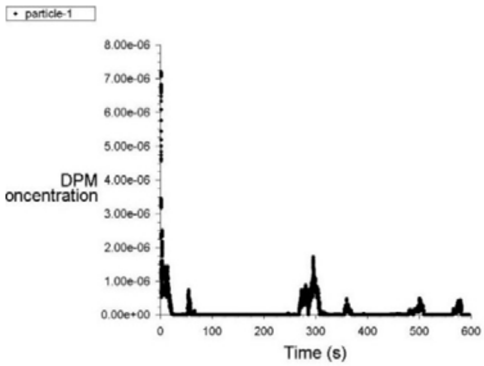
3.2.Simulation of aerosol particles



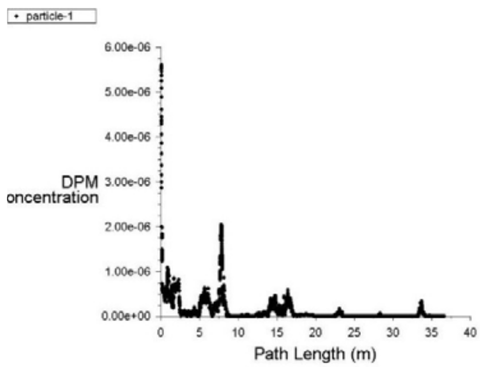
(a) Trajectory of particles



(b) Air flow vector



(c) concentration-time curve

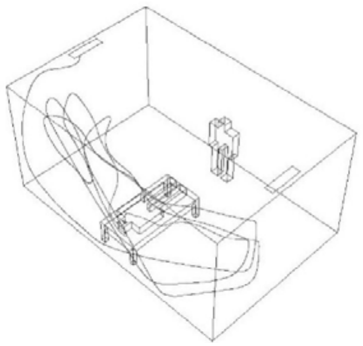


(d) concentration-path curve

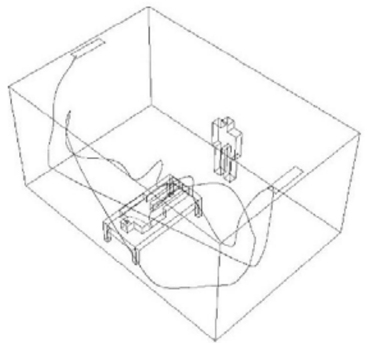
Figure 3. Simulation of 5microns aerosol particles

Figure 3 is the movement of 5 microns aerosol particles under the condition of 12 times per hour. As shown from the figure (a, b), trajectories of aerosol particles is mainly affected by the air flow organization. At the top of air, influenced by air supply outlet side, move to the right. Air forms vortex in the lower part of supply side. Be exhaled aerosol particles along with the indoor airflow direction of the movement, at the lower part of the supply side, do the spiral movement. After full mixing of fresh air and indoor air, move along the ground by back outlet. The advantage of this method is to control the activities of the aerosol particles, but the disadvantage is large distance of aerosol particle motion.

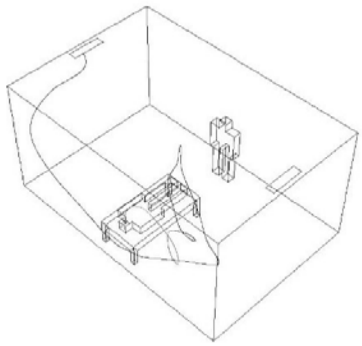
Figure (c, d) describes the aerosol particles concentration curve. As shown from the figure, be exhaled aerosol particles move upward and mixed with indoor air. The concentration of the aerosol particles start to reduce. Due to the influence of the vortex air flow, the concentration of aerosol particles in this area is large. After fresh air and indoor air complete mixing, aerosol particles concentration decrease to 0. Under the condition of wall attached jet, the concentration of aerosol particles closes to zero at long time. In the ward, aerosol particles concentration inhaled by medical staff is not up to the standard of the infection.



(a) 12 times per hour



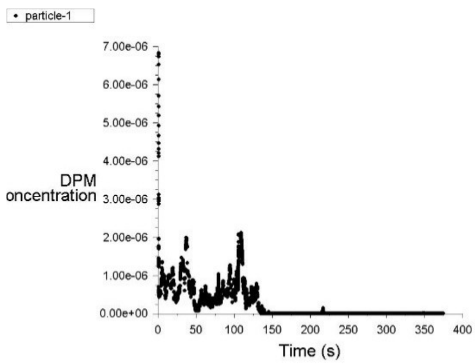
(b) 15 times per hour



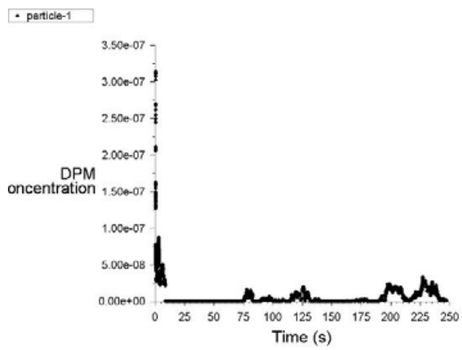
(c) 20 times per hour

Figure 4. 20 microns aerosol particles trajectory

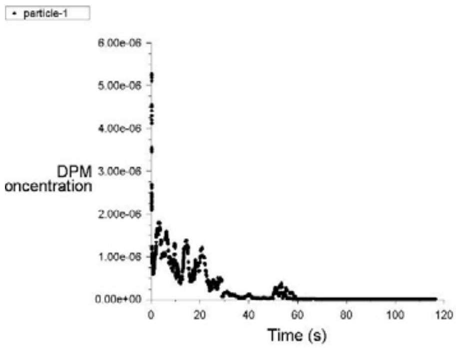
Figure 4 is the 20 microns aerosol particles trajectory in different air exchange rates. As shown from the figure, influenced by air flow, the aerosol particles all move to supply air side along indoor air. At the lower part of the supply side, in the process of fresh air and indoor air mixing, aerosol particles do the spiral movement. The larger air exchange rate leads to the greater pressure difference of indoor. The greater influence of air flow on aerosol particles leads to the result that the aerosol particles move a smaller distance indoors. When the air exchange rate is 12 times per hour, at the return side, the indoor air and ground air exchange heat and mass. Air flow forms vortex in the return side lower part, which increases the aerosol particles path length. When the air exchange rate is 20 time per hour, under the influence of pressure difference, the return side air move to the supply air side, which decrease heat and mass exchange with ground air. The vortex intensity decreases, and the aerosol particles path length also decrease. Therefore, increasing air exchange rate can control the movement direction of indoor air, which is conducive to reduce the aerosol particles indoor path length.



(a) 12 times per hou



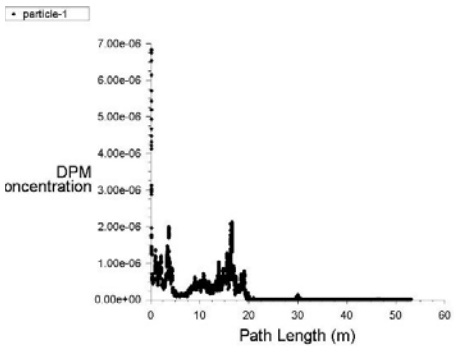
(b) 15 times per hour



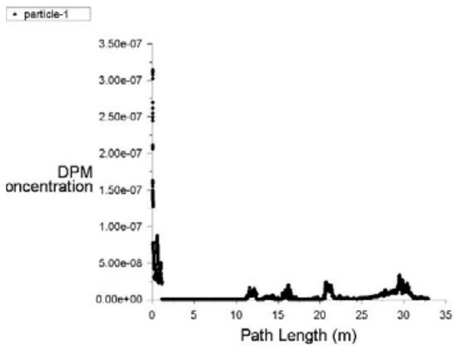
(c) 20 times per hour

Figure 5. 20 microns aerosol particles time-concentration curve

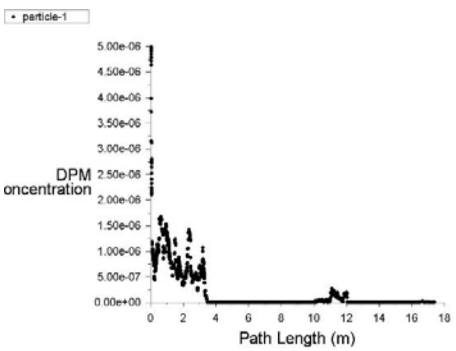
Figure 5 is 20 microns aerosol particles time-concentration curve. As shown from figure, the aerosol particles move in the air flow vortex and the aerosol particles concentration is very high at the beginning. Aerosol particles concentration decrease gradually and remain stable after mixing. By comparison, the greater air exchange rate is, the shorter time aerosol particles movement needs. When air exchange rate is 12 times per hour, exhausting aerosol particles need nearly 400 seconds. When it is 15 times per hour, exhausting needs nearly 250 seconds. When it is 20 times per hour, exhausting needs nearly 120 seconds. In addition, when air exchange rate is large, the time that aerosol particles concentration reduces to steady state is also shorter. At the condition of 20 times per time, this process needs 20 seconds. But at the condition of 12 times per hour, this process needs nearly 150 seconds. When air exchange rate is small, the high aerosol particles concentration is easy to cause infection to the medical staff.



(a) 12 times per hour



(b) 15 times per hour



(c) 20 times per hour

Figure 6. 20 microns aerosol particles path-concentration curve

Figure 6 is 20 microns aerosol particles path-concentration curve. As shown from figure, when air exchange rate is 12 times per hour, aerosol particles are affected by air flow vortex. They are at the bottom of the supply side movement nearly 20 meters. In this process, the aerosol particles concentration almost has no decreasing trend. In other words, at this area, medical staffs are at risk of infection. When the concentration of aerosol particles decreases to a steady state, the path length of aerosol particles is nearly 55 meters. While increasing air exchange rate, concentration of aerosol particles accelerated decline and the path length is shorter. When the air exchange rate is 20 times per hour, aerosol particles concentration decreases to 0 after moving 4 meters. The whole path length indoor is less than 18 meters. The aerosol particles do not accumulate in the ward in the whole process, which effectively reduce the medical staff of inhaled aerosol particles concentration.

4. Discussion

Aerosol particles in the air affected by multiple forces, such as gravity, Saffman force, Basset force, drag force, Brown force and so on. According to the size of the force, the smaller force can be ignored. This will also cause the error of the result. As usual, the gravity and Saffman force have a great effect on the result, which are not allowed to ignore. The evaporation of the aerosol particles is very common, especially for the big aerosol particles. In this paper, choosing the 5μm and 20 μm aerosol particles can reduce the influence of evaporation. The simulation is more authenticity. As shown in results, bigger air exchange rate is more effective, but in the ward, we must consider the patients' comfort. So air exchange rate should be moderate. Both can improve indoor air quality, and satisfy the patients' comfort.

5. Conclusions

The main conclusions can be drawn as follows:

- In three kinds of air exchange rates, supply air can produce good wall attached jet.
- When air exchange rate is 12 times per hour, indoor air is less affected by the air flow, which is easy to form vortex. When air exchange rate is 20 times per hour, air flow can effectively control the direction of movement of indoor air.
- The larger air exchange rate is, the shorter aerosol particles path length is, the faster concentration decreases, the less time stay indoors.
- The ventilation in injection ward can use wall attached jet. This method can avoid aerosol particles without regular movement. In the condition allow, air exchange rate of 20 times per hour is good to ensure indoor air quality.

Acknowledgements

This research was supported by National Natural Science Funds (51378318), Innovation Team Project of Liaoning Province Universities (LT2013013), and Shenyang Technology Program (F11-261-17).

References

[1] W.P.Deng, J.M.Shen, X.Q.Tang, D.Q.Shen, The study on the optimization of indoor air distribution for SARS isolation wards, Buikking Energy and Environment, 24(2) (2005) 9-14.

[2] X.T.Wu, Thinking and design practice of the hospital air conditioning and ventilation system, Heating Ventilation & Air Conditioning, 33(5) (2003), 6-12.

[3] Y.Q.Di, Q.Q.Wang, Z.L.Xu, Experiment research and numerical simulation of infectious isolation wards reasonable ventilation, Contamination Control & Air-conditioning Technology, (2) (2005), 1-4.

[4] Q. Chen, Comparison of different k-ε models for indoor air flow computations, Numerical Heat Transfer, Part B Fundamentals, 28(3) (1995), 353-369.

[5] C.Q.Yang, B.Zhao, X.D.Yang, Liu.S.K, Comparison of three simulation methods of indoor particle dispersion, Heating Ventilation & Air Conditioning, 37(4) (2007), 7-11.